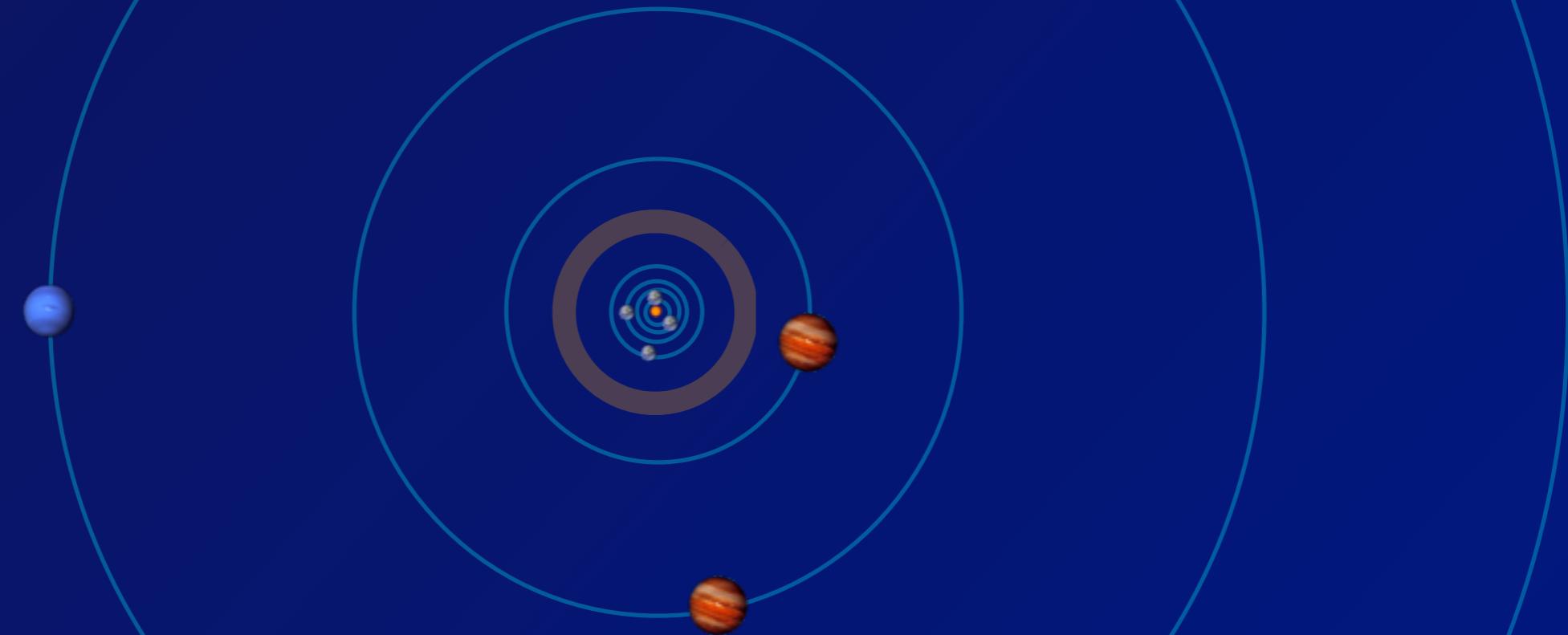
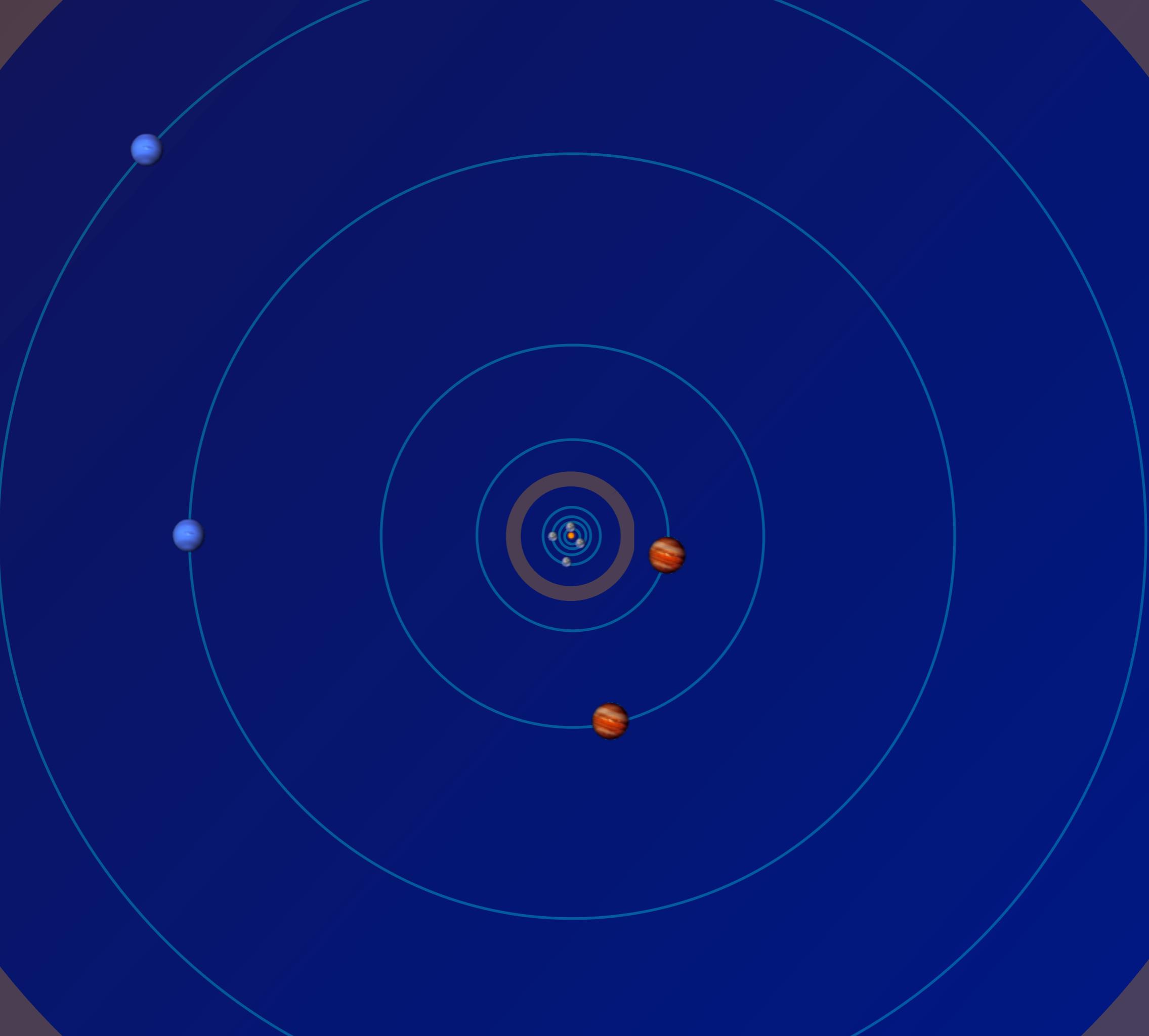


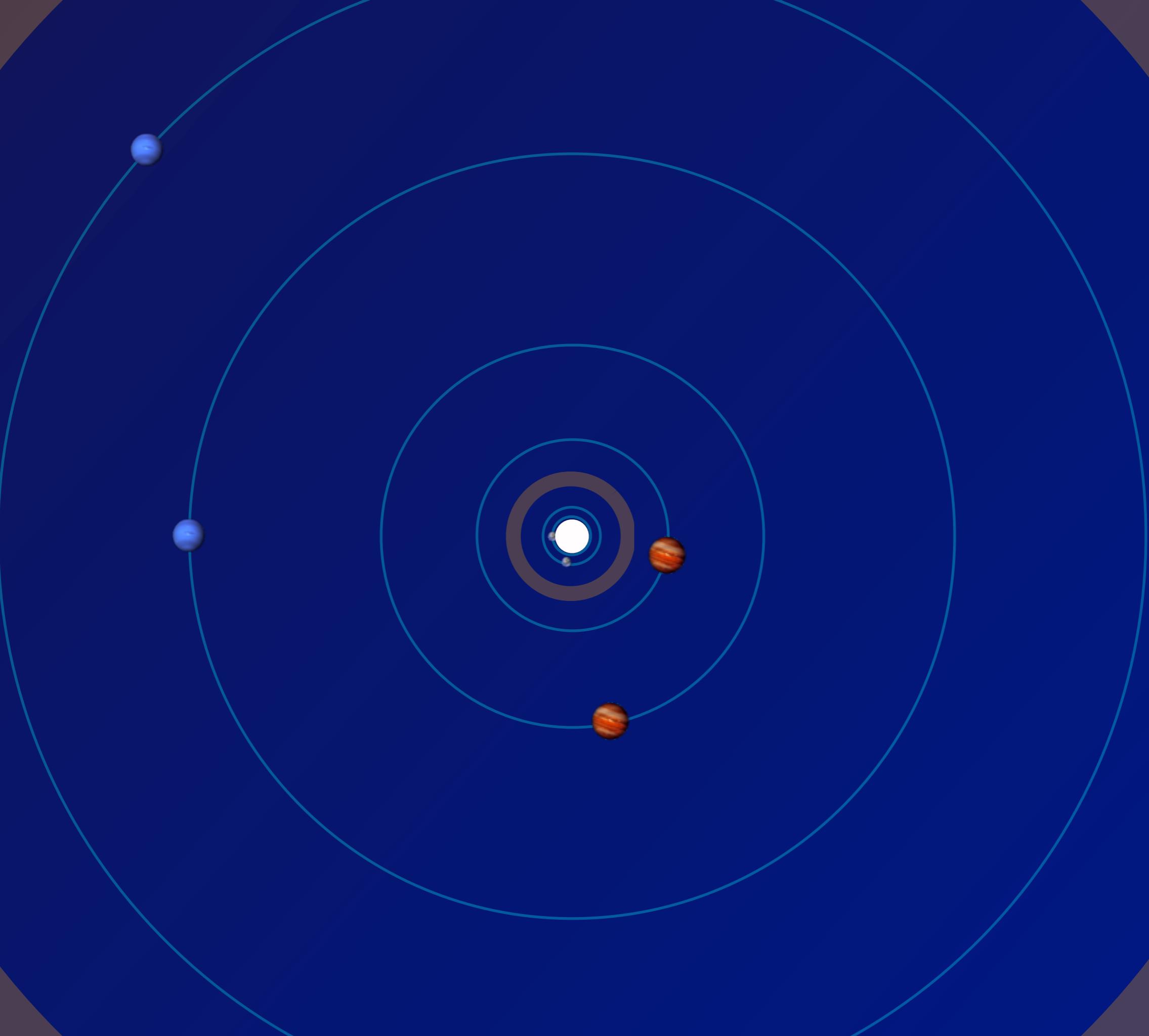
Demographics of Giant Planets

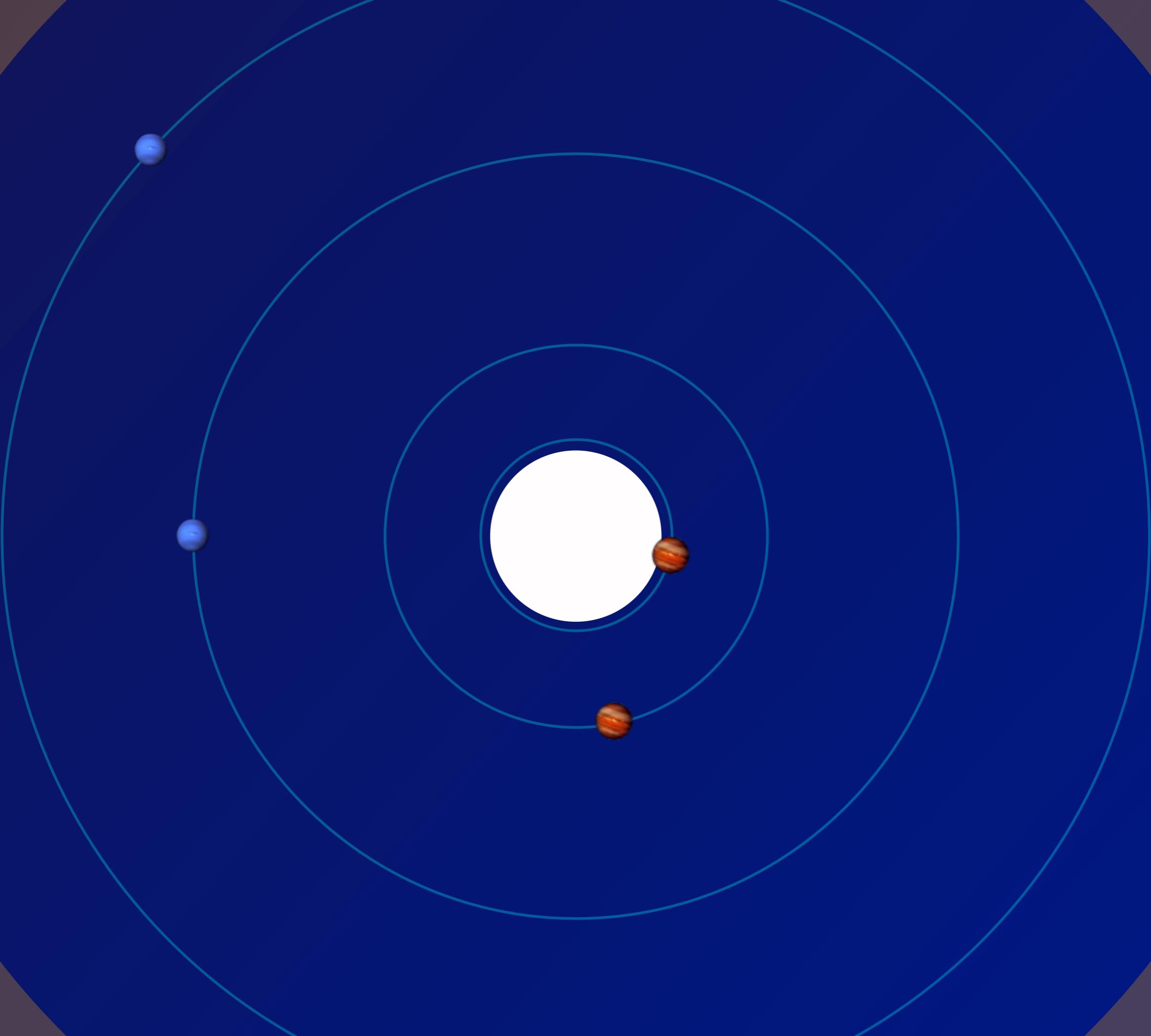
Insights from Theory

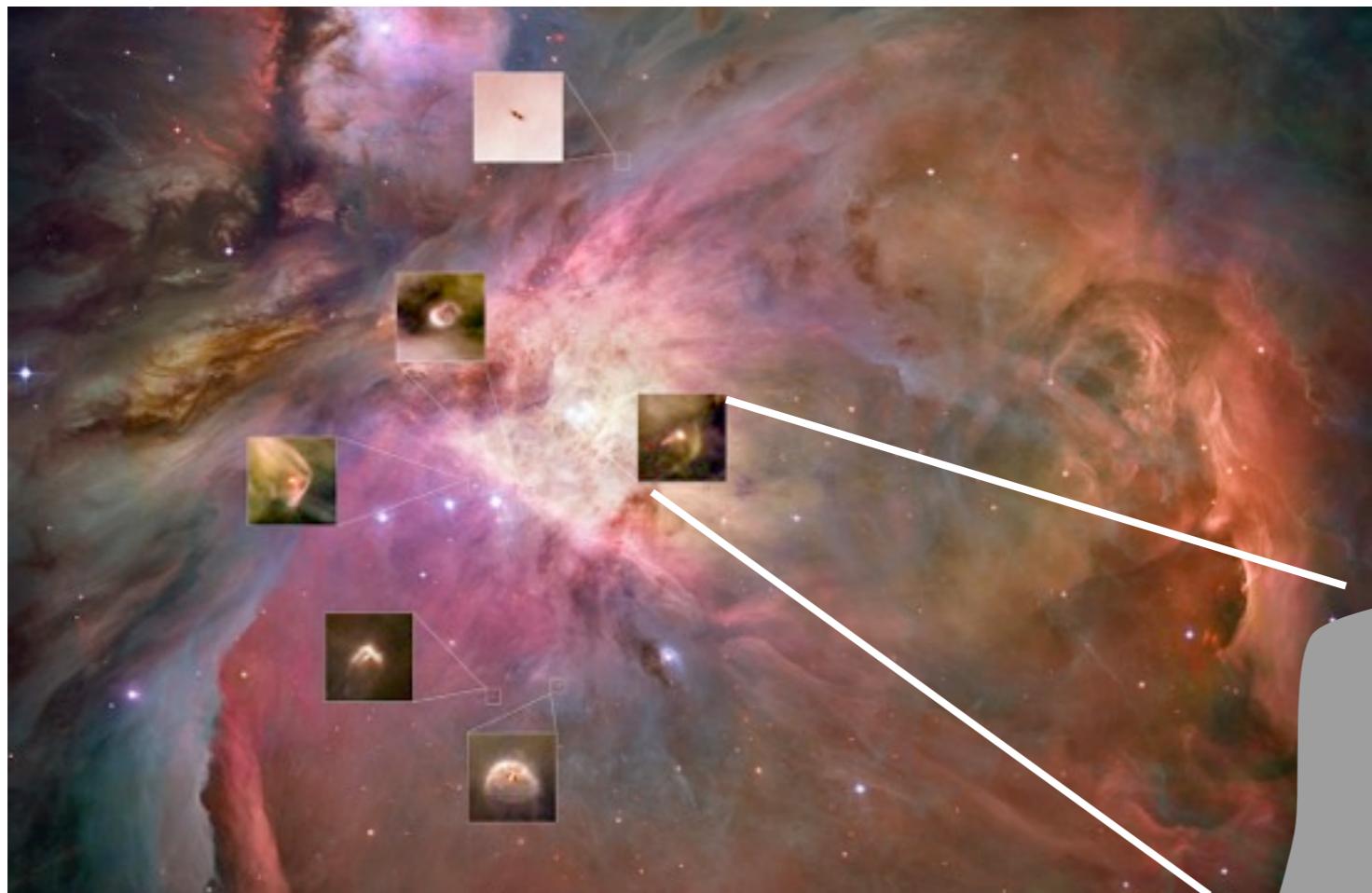


Ruth Murray-Clay
Harvard-Smithsonian Center for Astrophysics

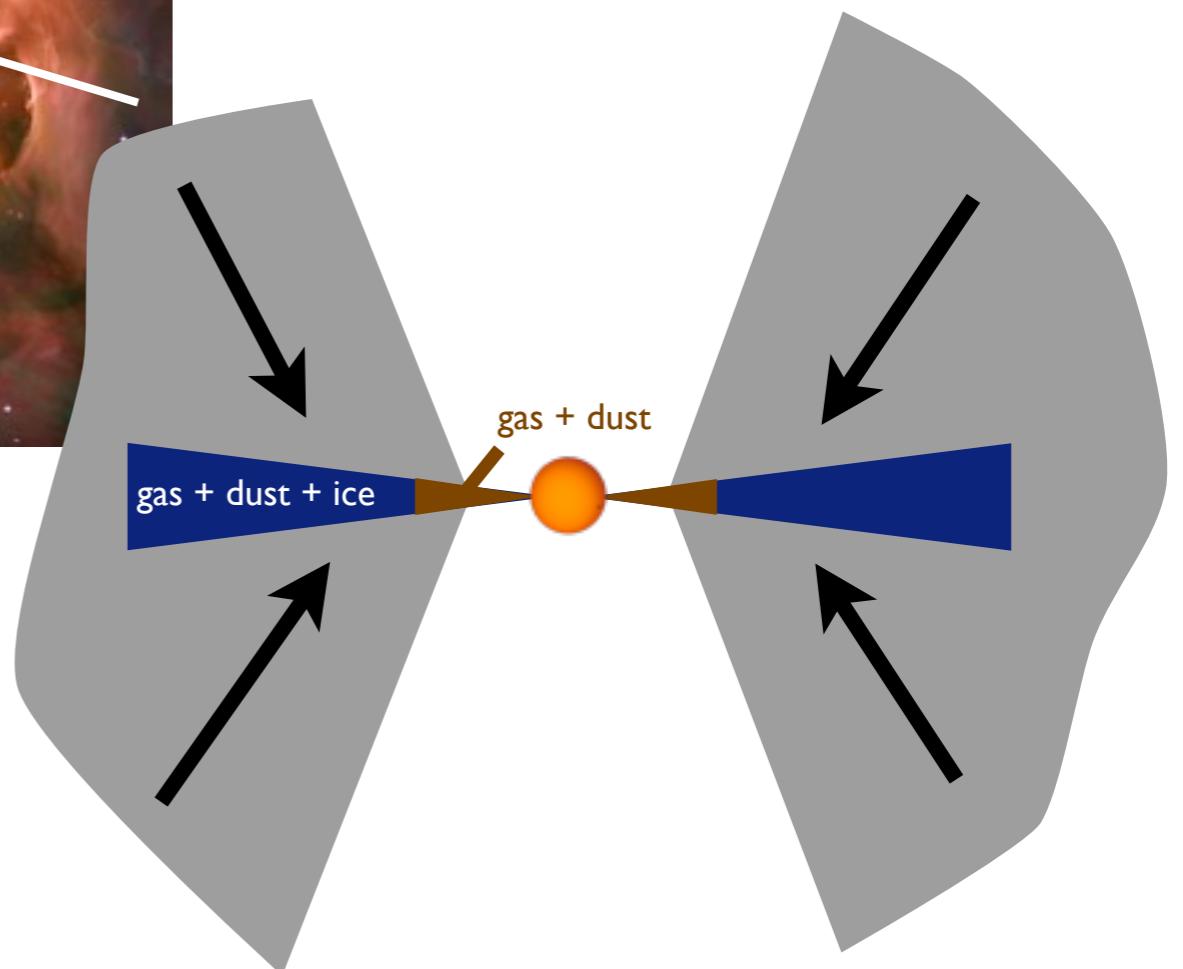




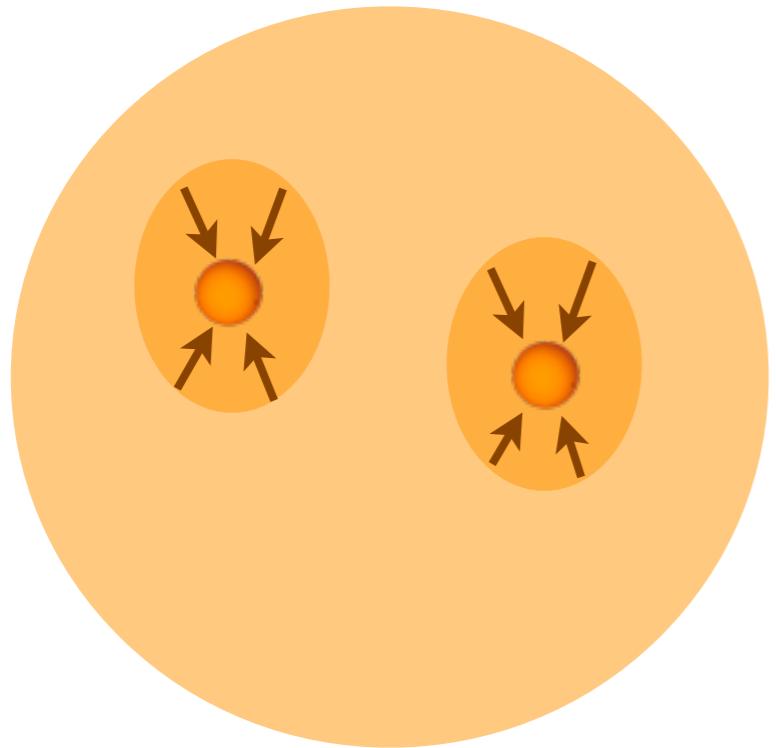




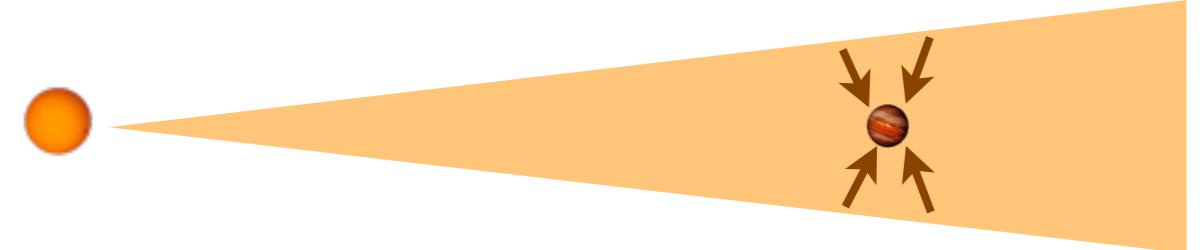
NASA, ESA, M. Robberto, HST Orion Treasury Project, L. Ricci



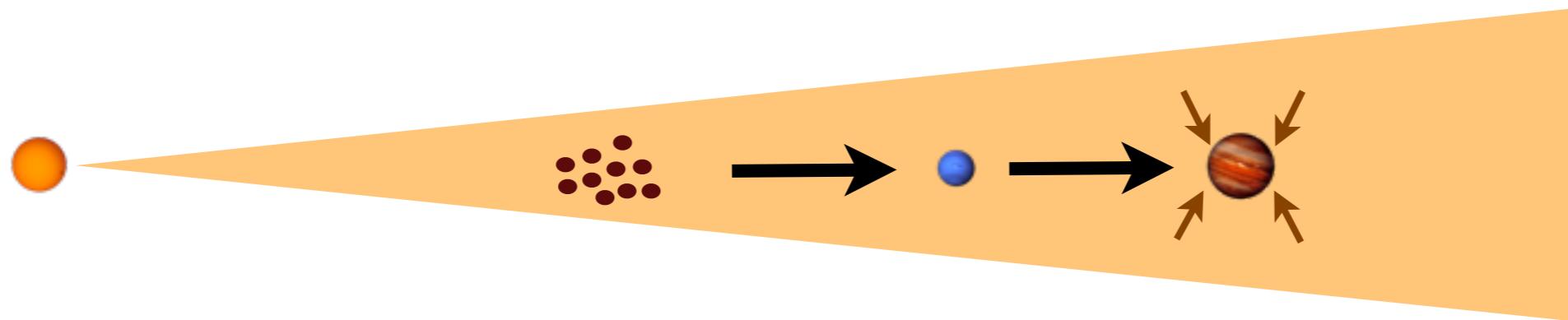
Three ways to form companions



turbulent fragmentation



gravitational instability

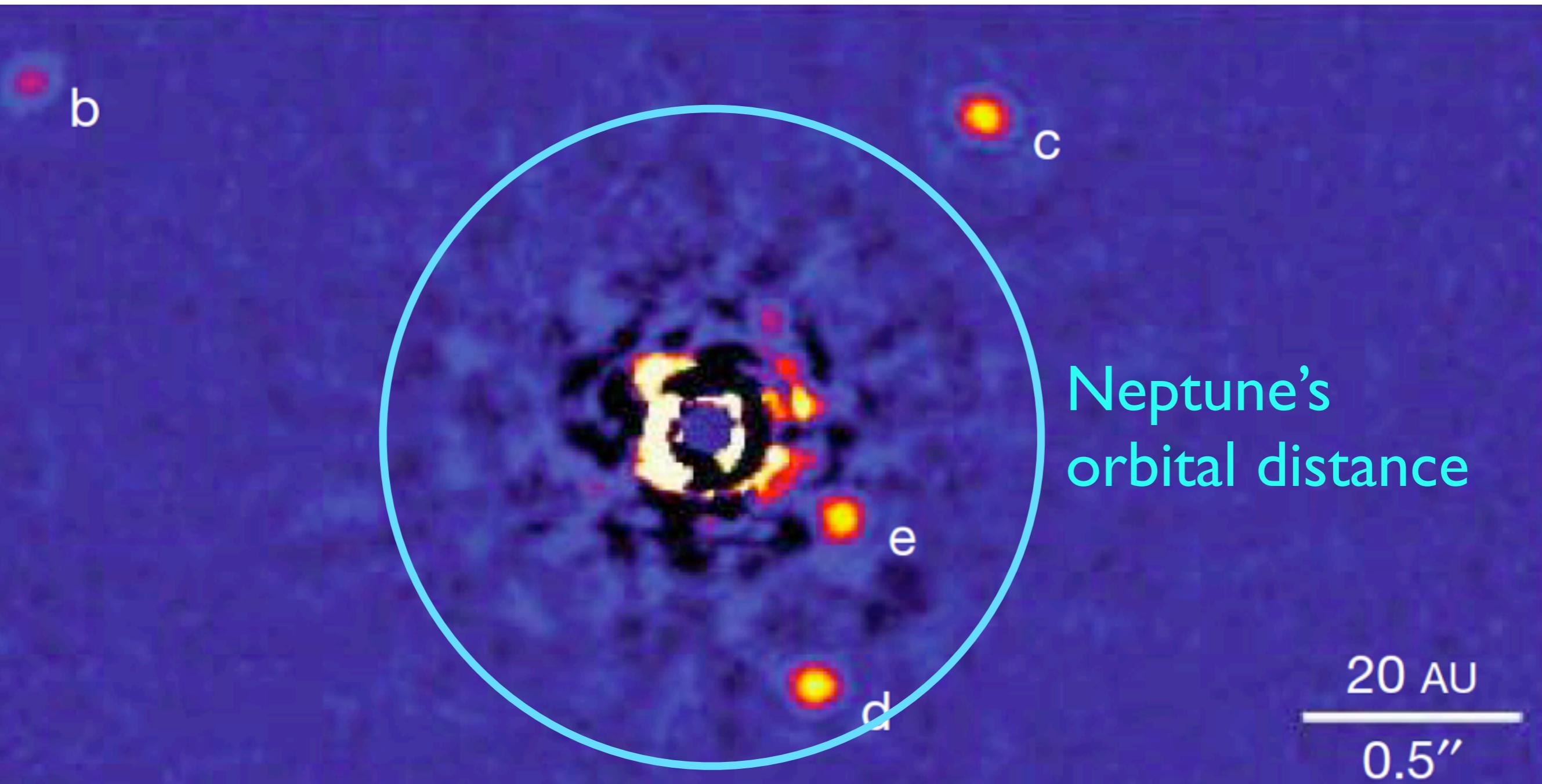


core accretion

Theory can't predict numbers,
but it can predict patterns in:

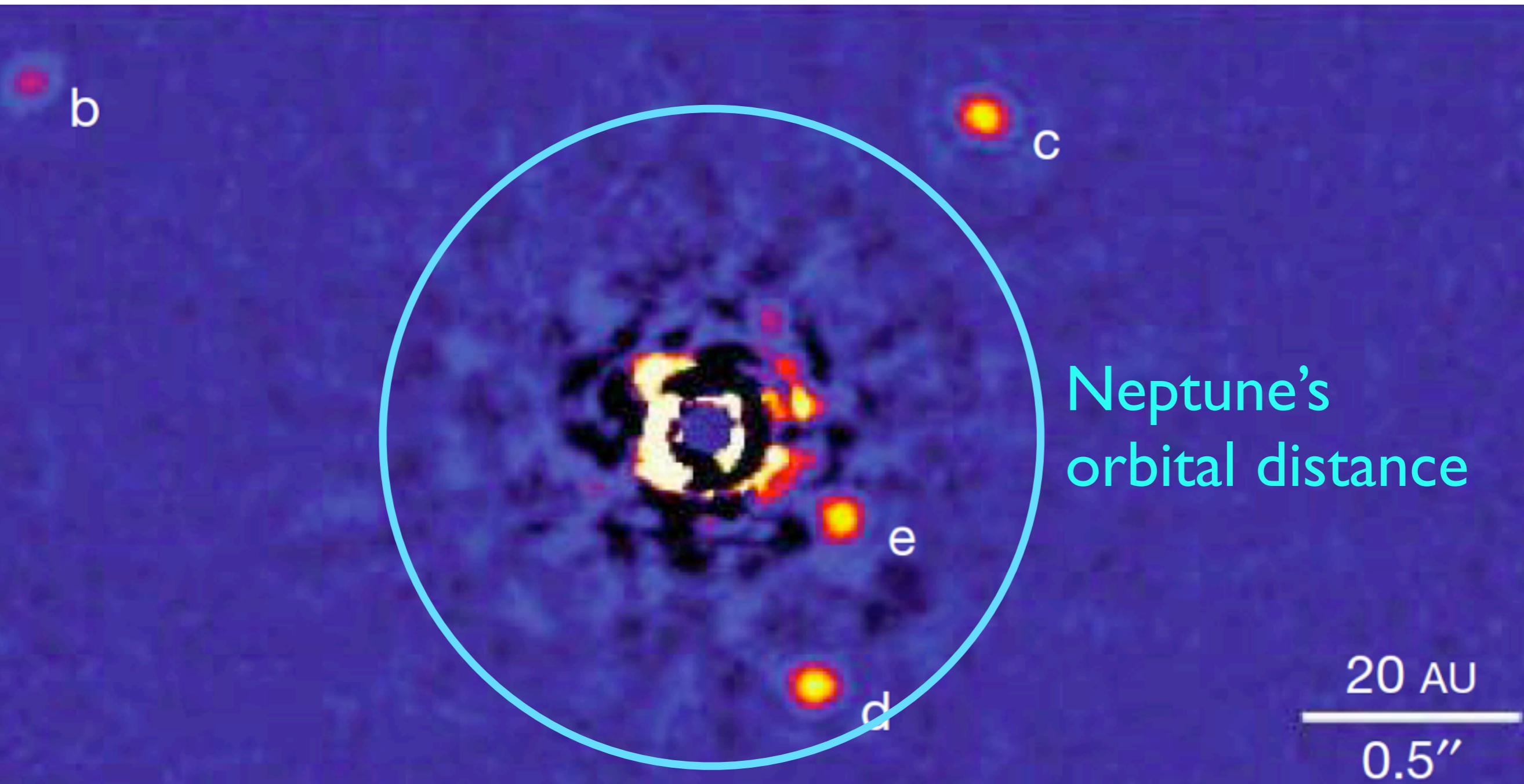
- statistical populations
- system architectures (rather than individual planets)

HR 8799: A testbed for planet formation theories



Marois et al. 2010

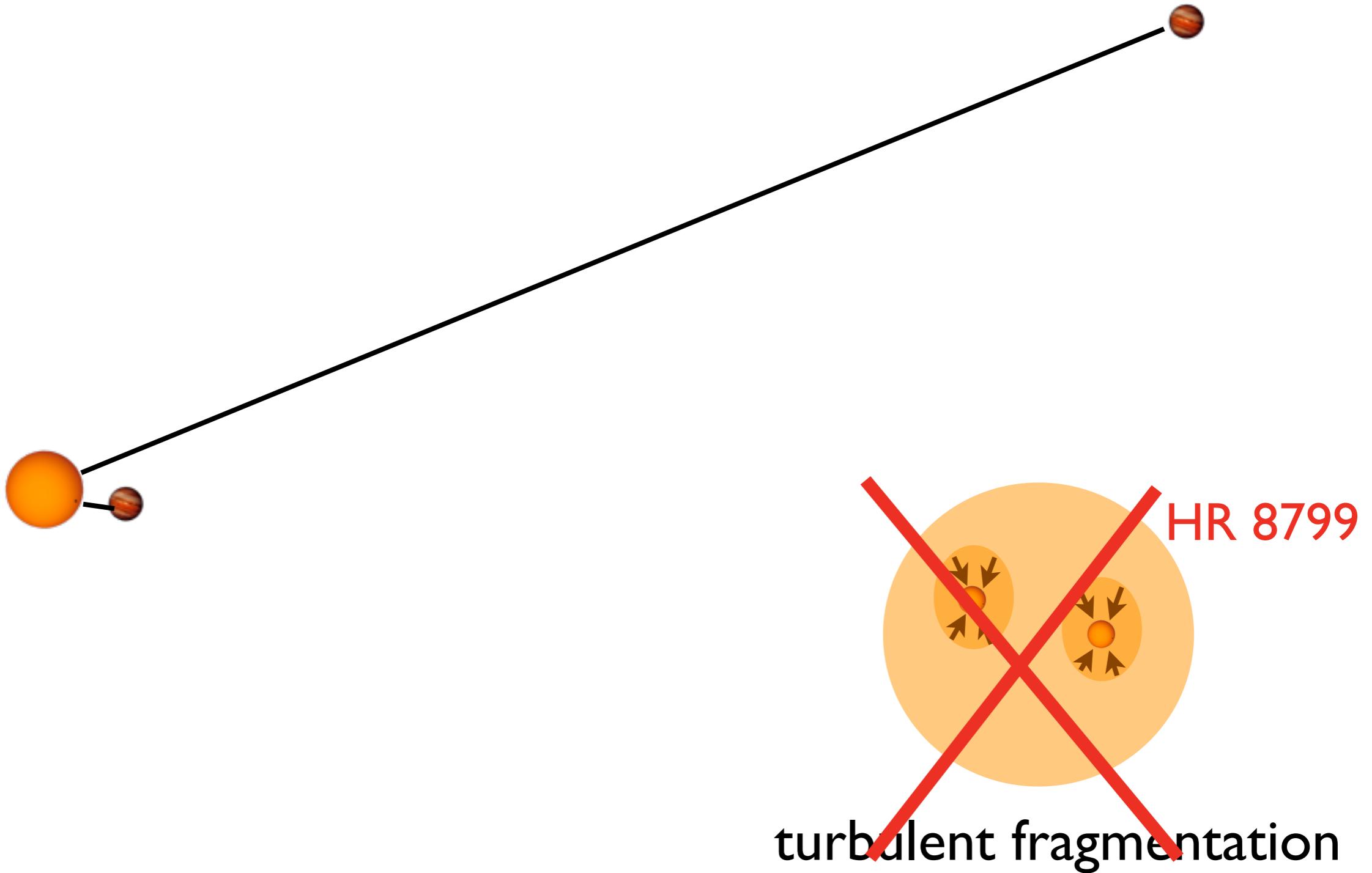
HR 8799: A testbed for planet formation theories



Marois et al. 2010

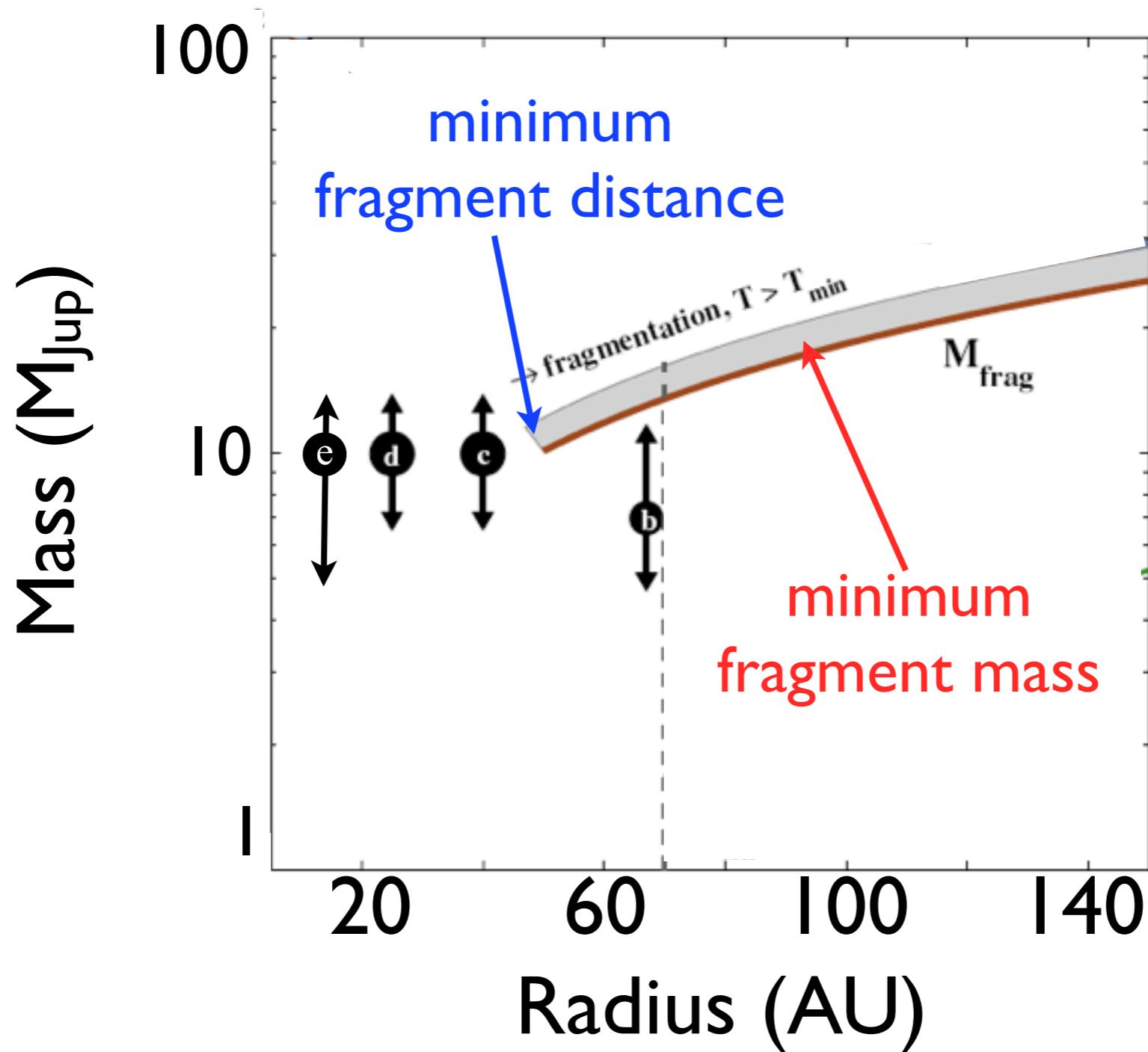
big planets or small stars?

A system architecture test: The HR 8799 system is not heirarchical



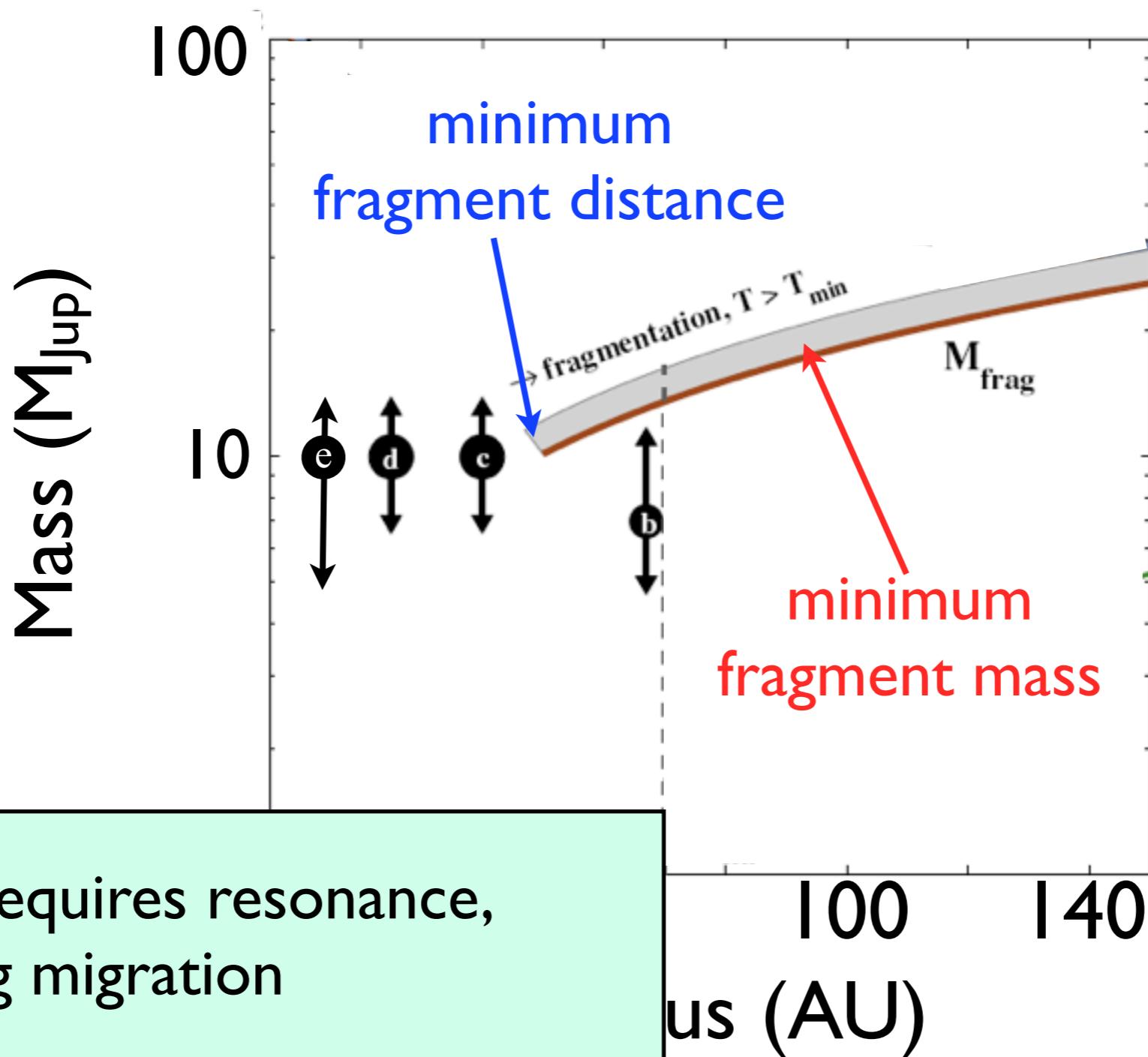
Gravitational Instability?

Planets cannot grow after fragmentation and they must migrate in



Gravitational Instability?

Planets cannot grow after fragmentation and they must migrate in

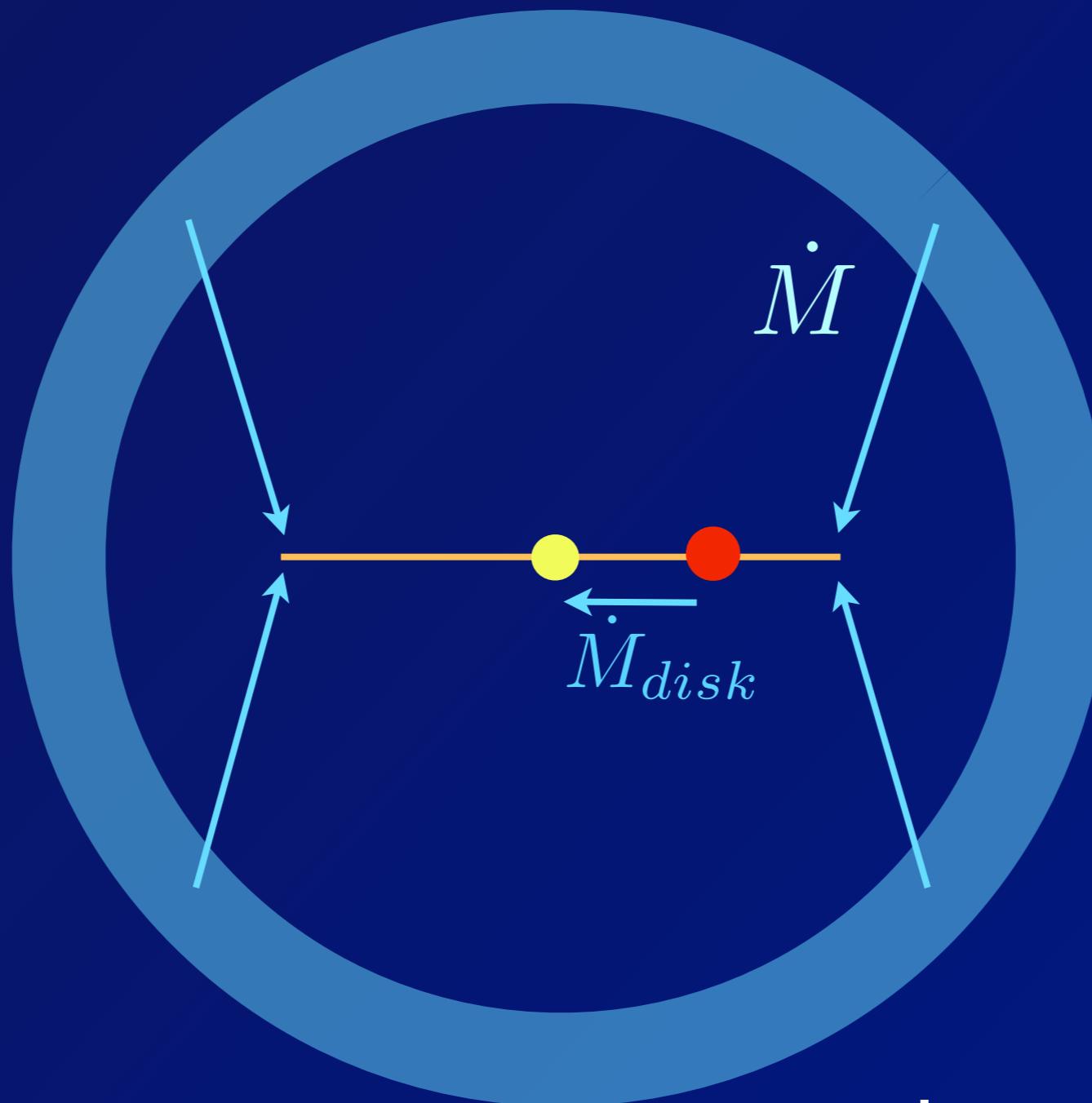


Stability requires resonance,
suggesting migration

Fabrycky & Murray-Clay 2010

Kratter, Murray-Clay, & Youdin, ApJ 2010

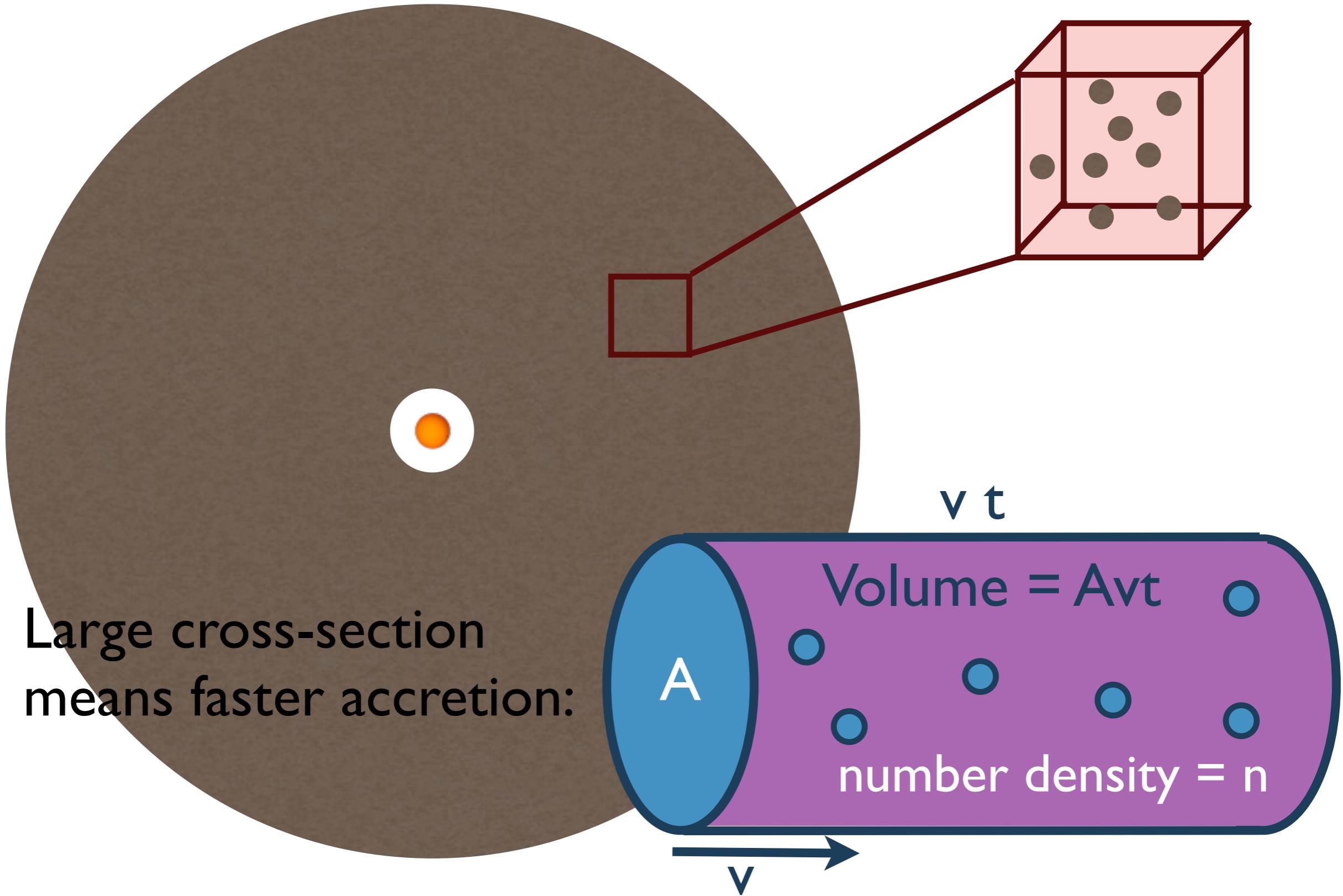
Collapse must occur at the end of infall
or the fragment will grow into a binary star



isolation mass is stellar!

Core accretion:

Need to grow a massive solid core through collisions

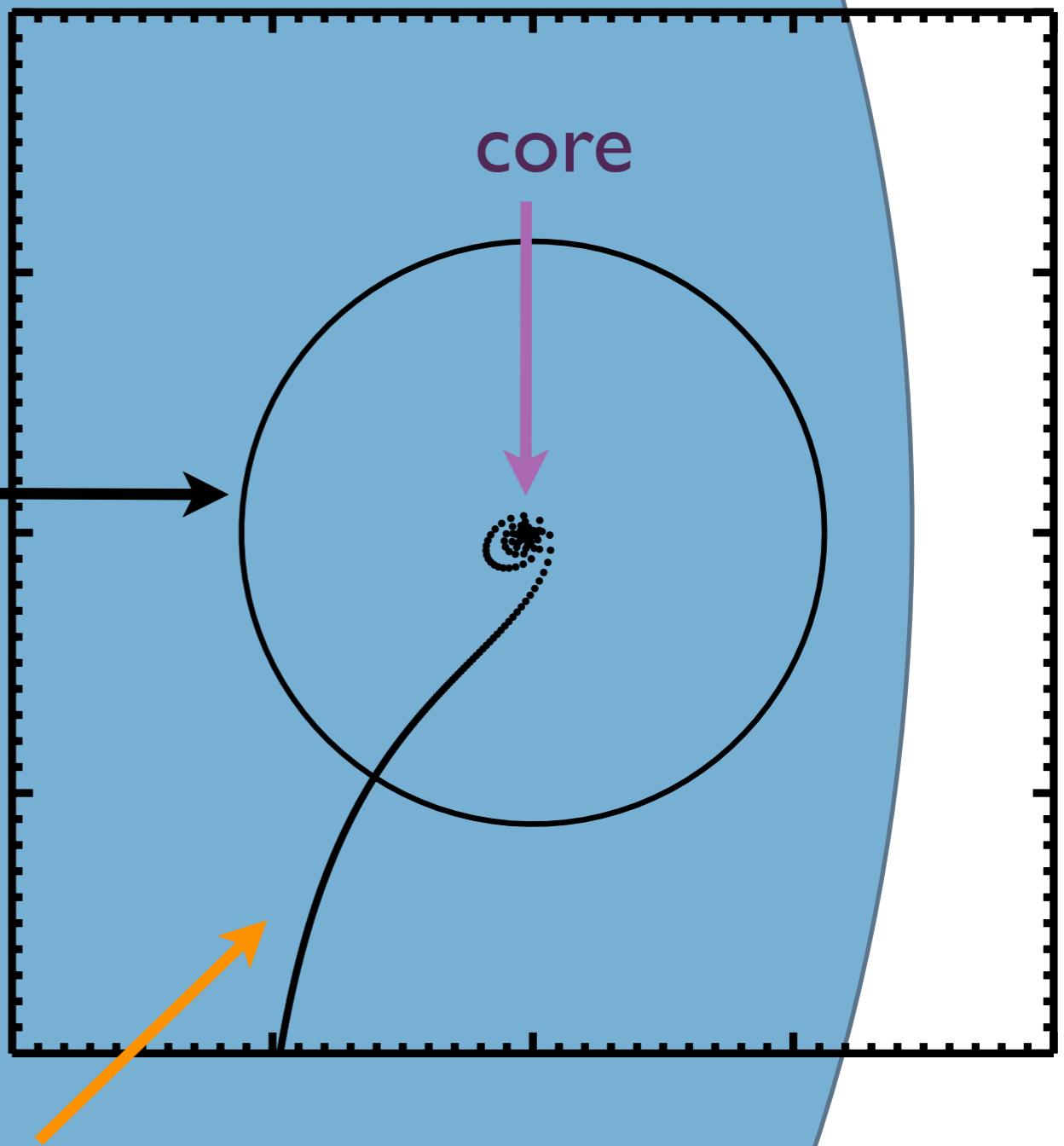


Capture by gas drag increases the cores' accretion cross-section

Sun

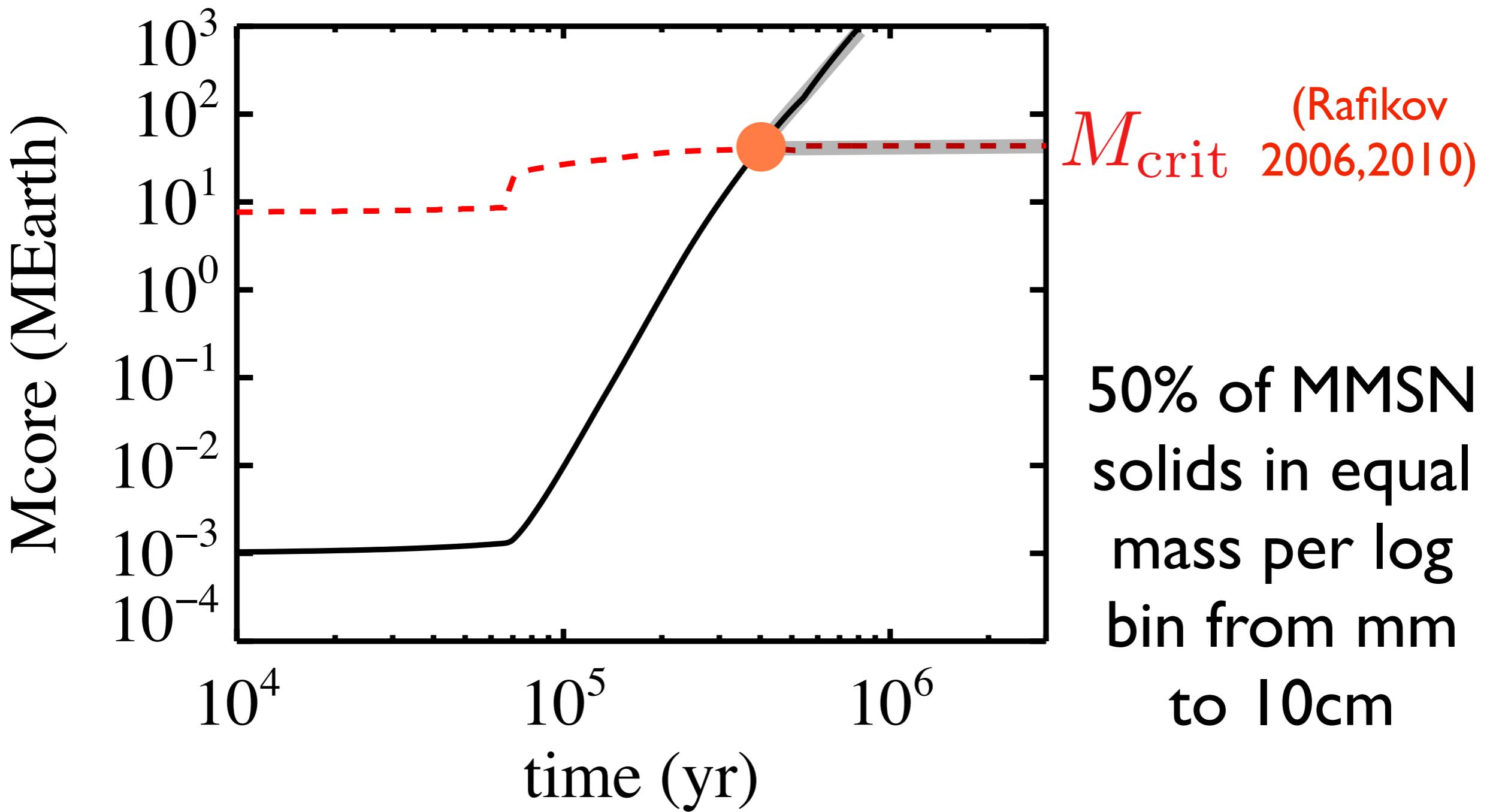
capture can
extend to
the Hill radius

planetesimal

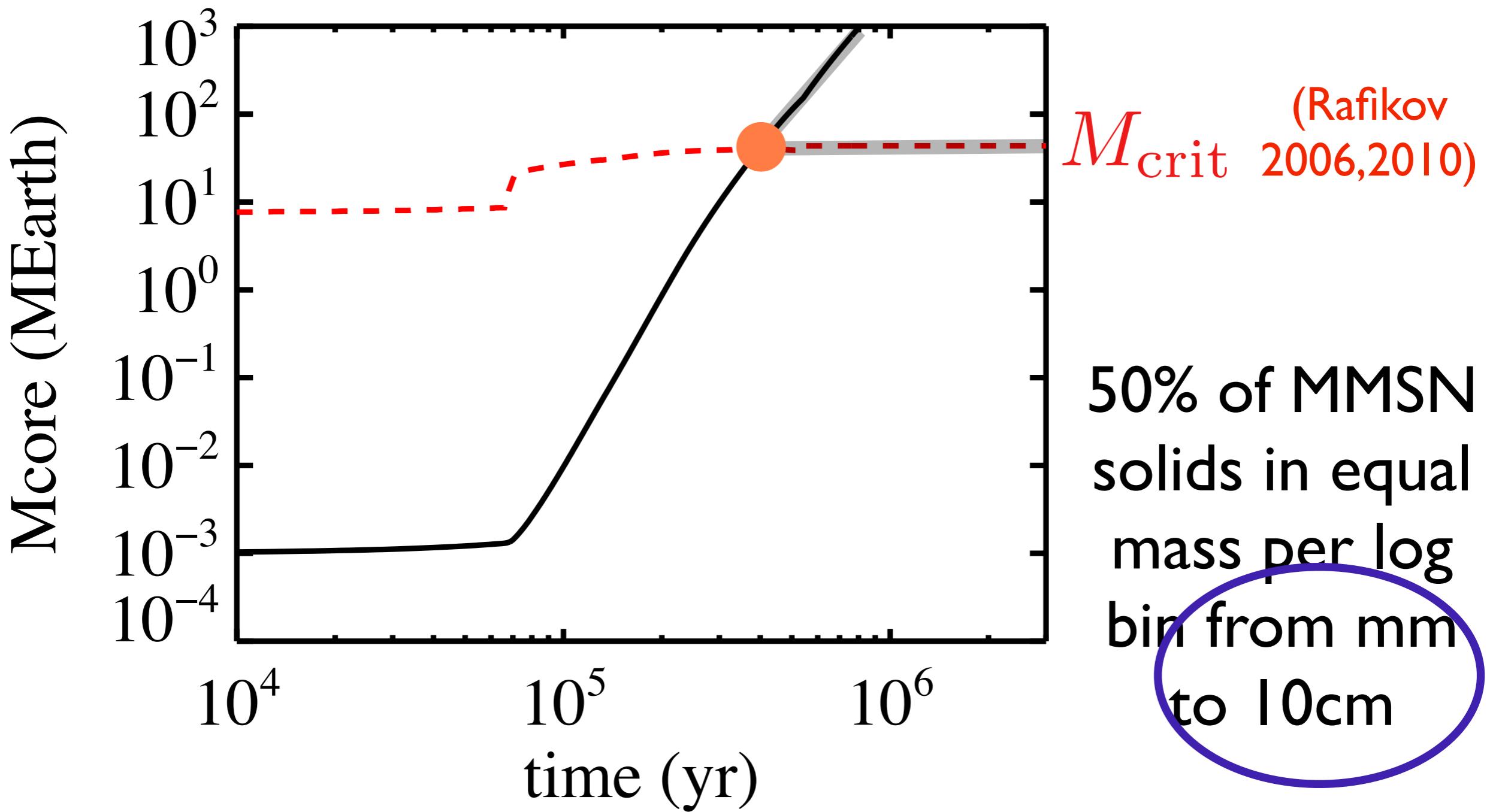


Murray-Clay et al., in prep
see also: Ormel & Klahr 2010,
Lambrechts & Johansen 2012

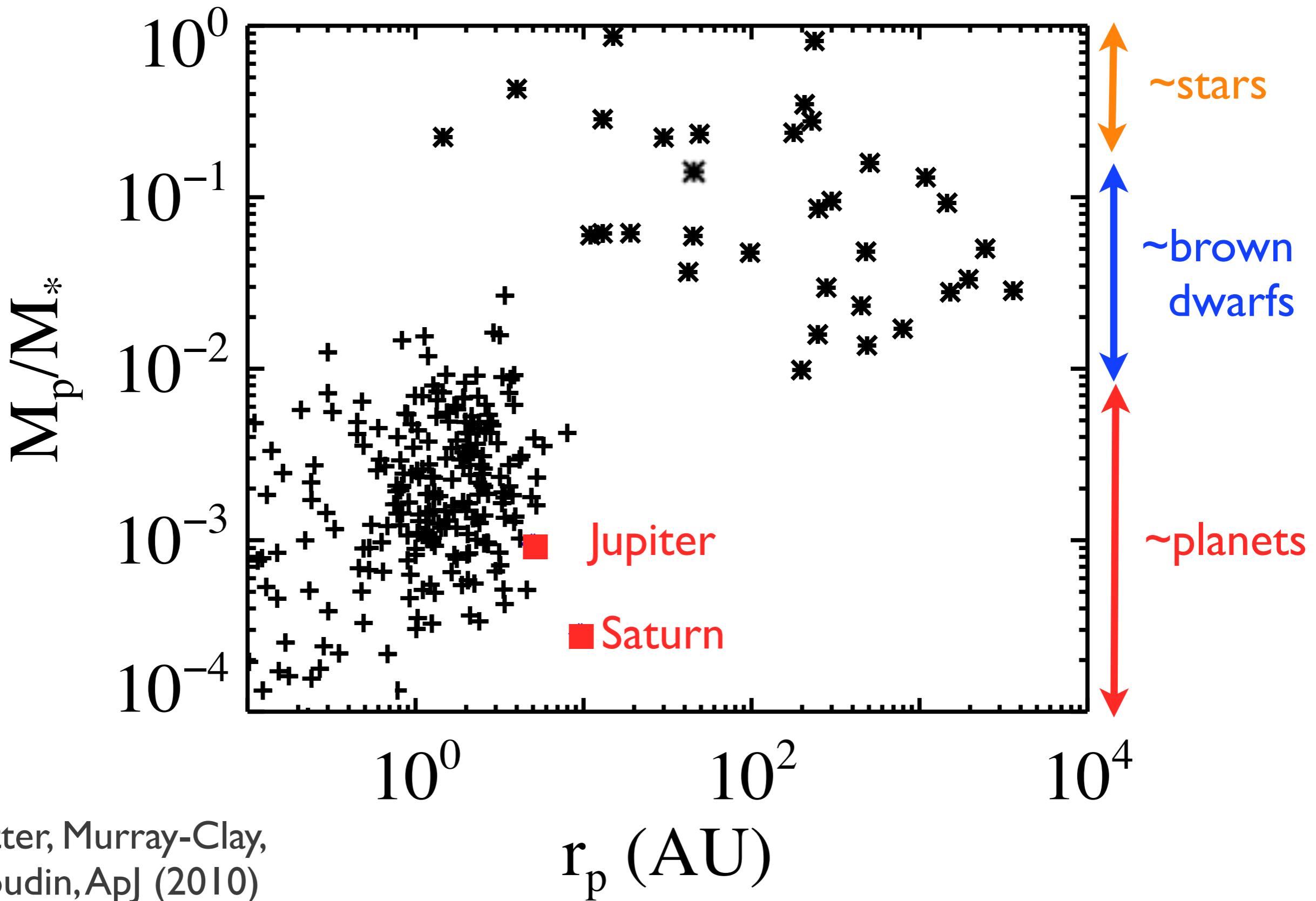
Growth times at 70 AU can be short enough to nucleate an atmosphere



Growth times at 70 AU can be short enough to nucleate an atmosphere



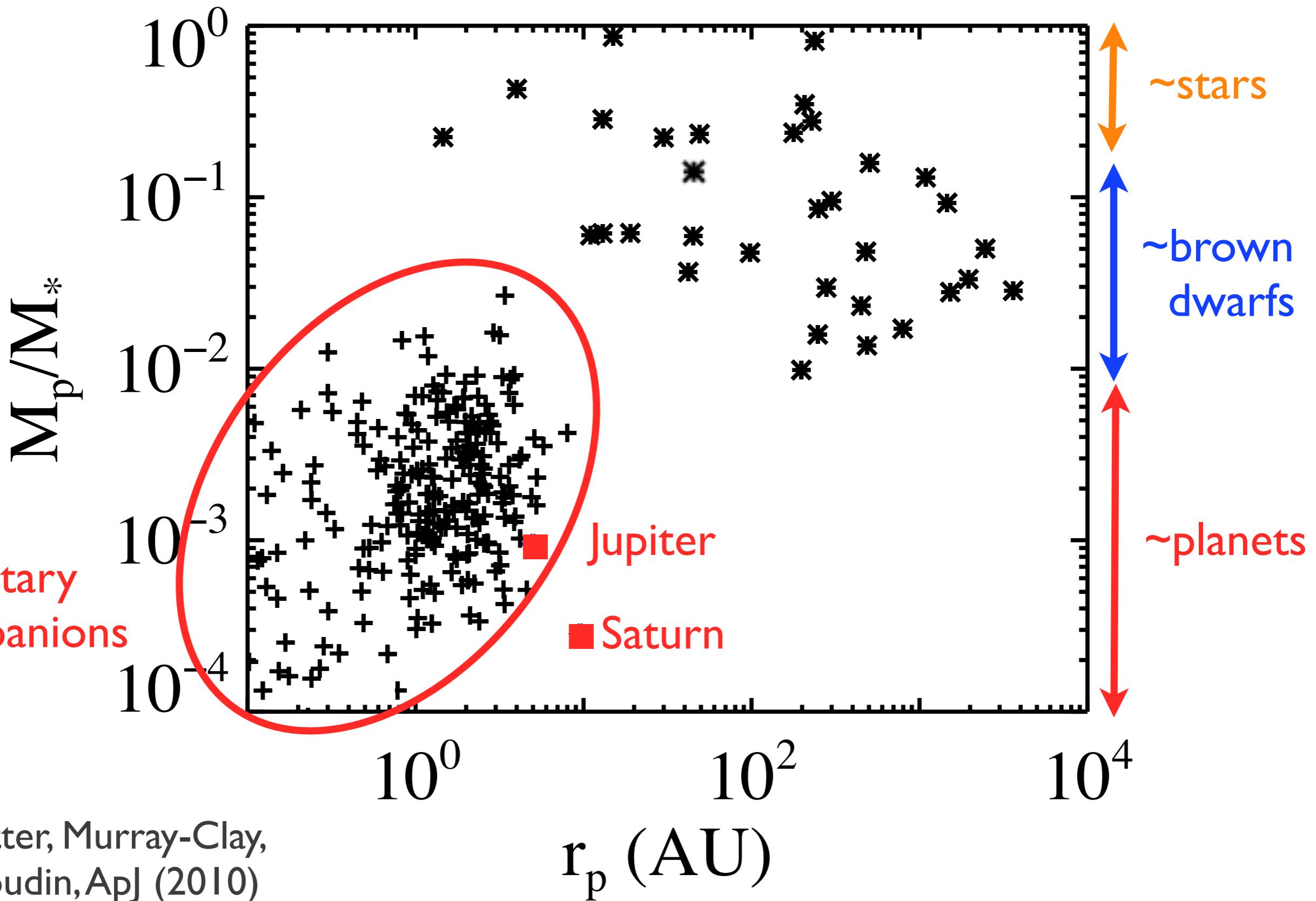
Test case HR 8799: Brown Dwarfs or Planets?



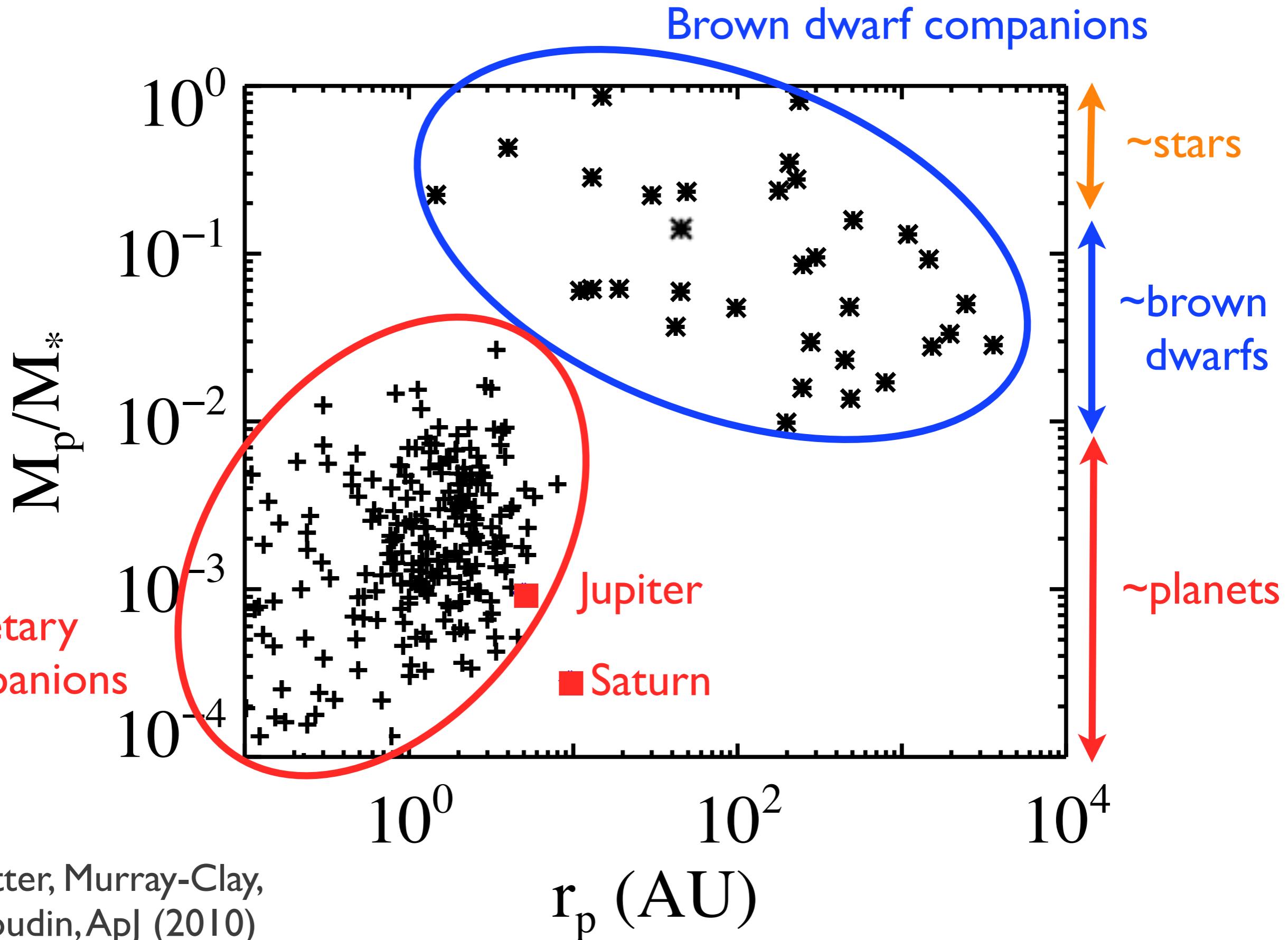
Kratter, Murray-Clay,
& Youdin, ApJ (2010)

Data: Zuckerman & Song 2009; exoplanet.eu

Test case HR 8799: Brown Dwarfs or Planets?



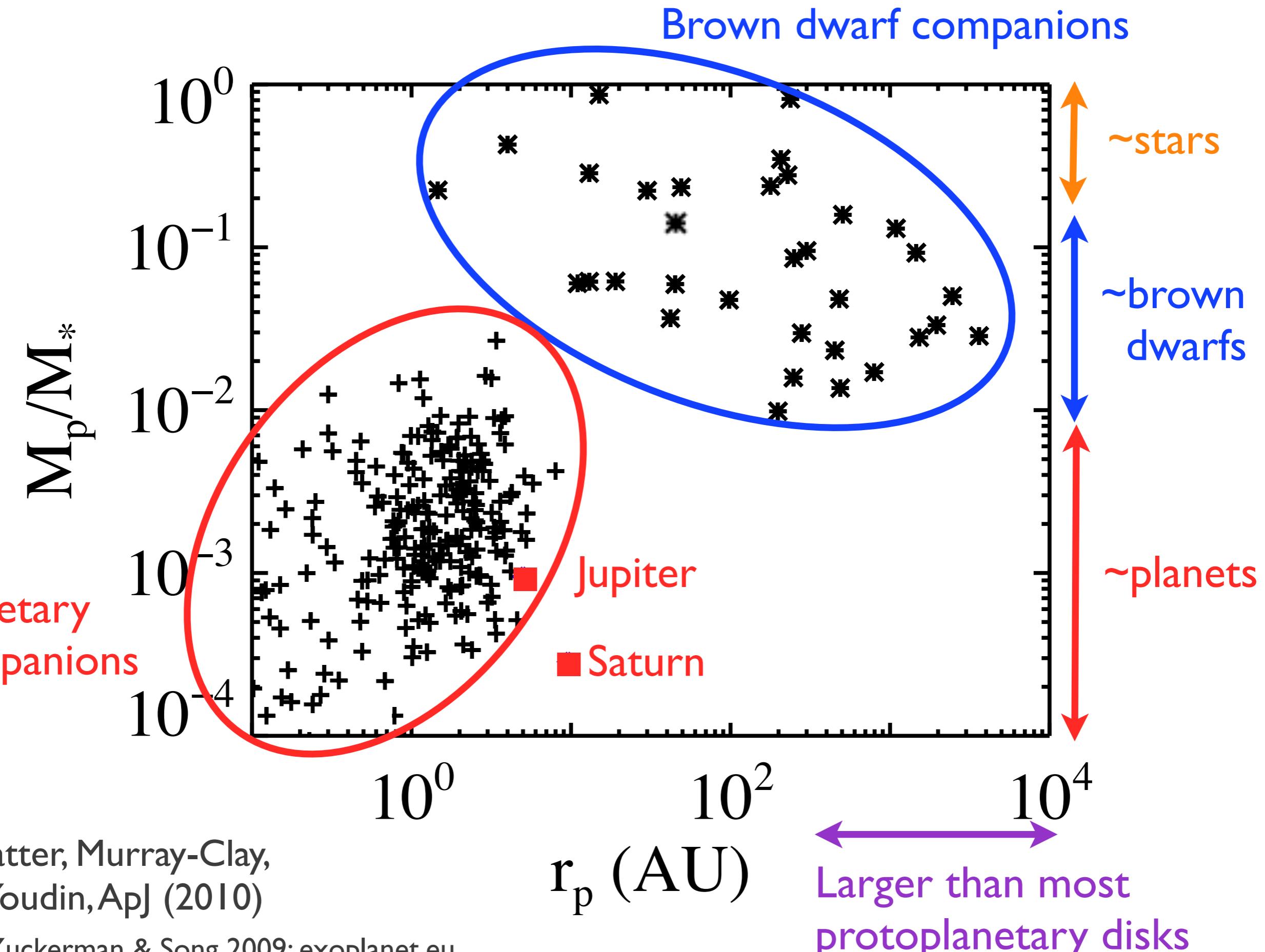
Test case HR 8799: Brown Dwarfs or Planets?



Kratter, Murray-Clay,
& Youdin, ApJ (2010)

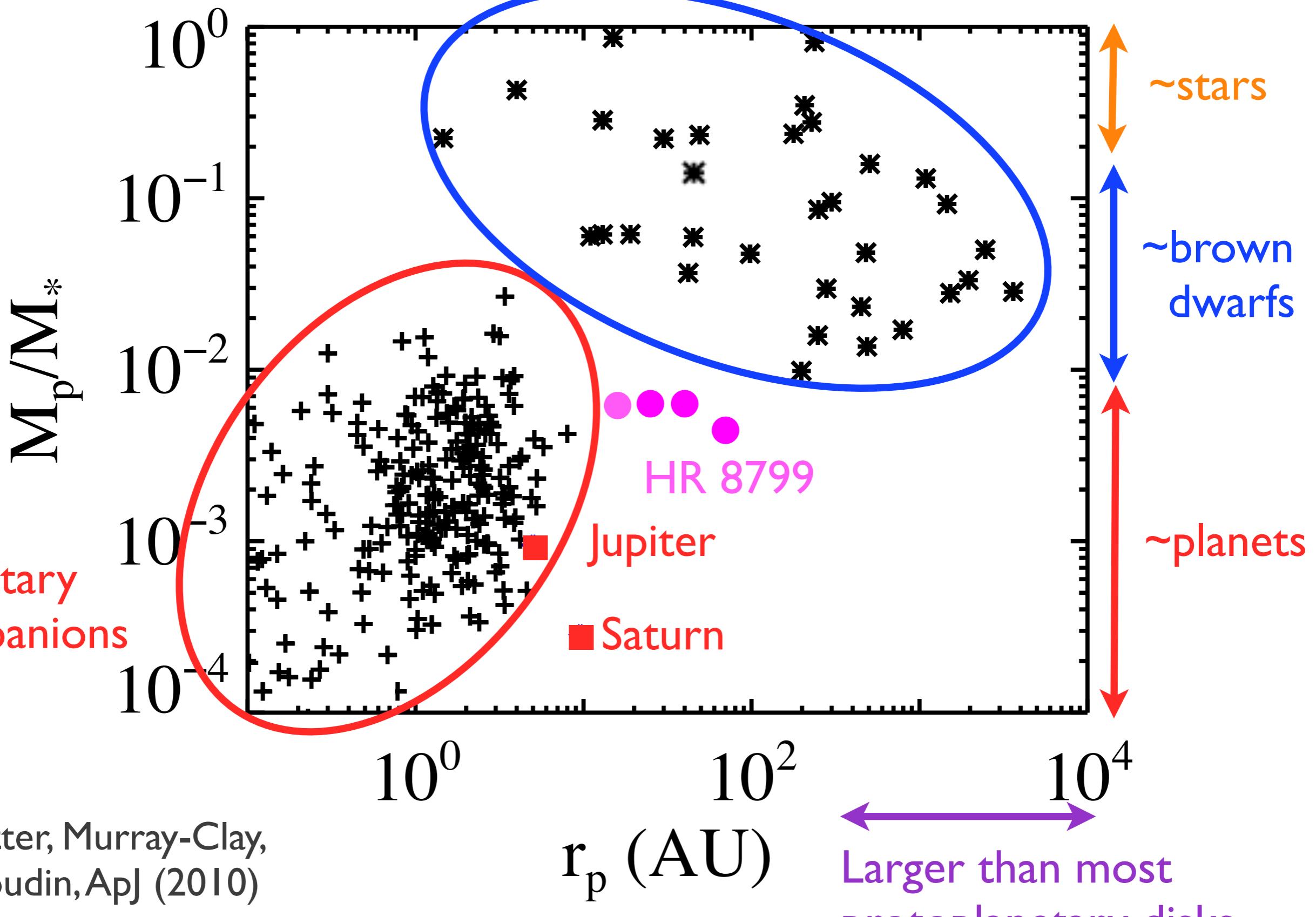
Data: Zuckerman & Song 2009; exoplanet.eu

Test case HR 8799: Brown Dwarfs or Planets?



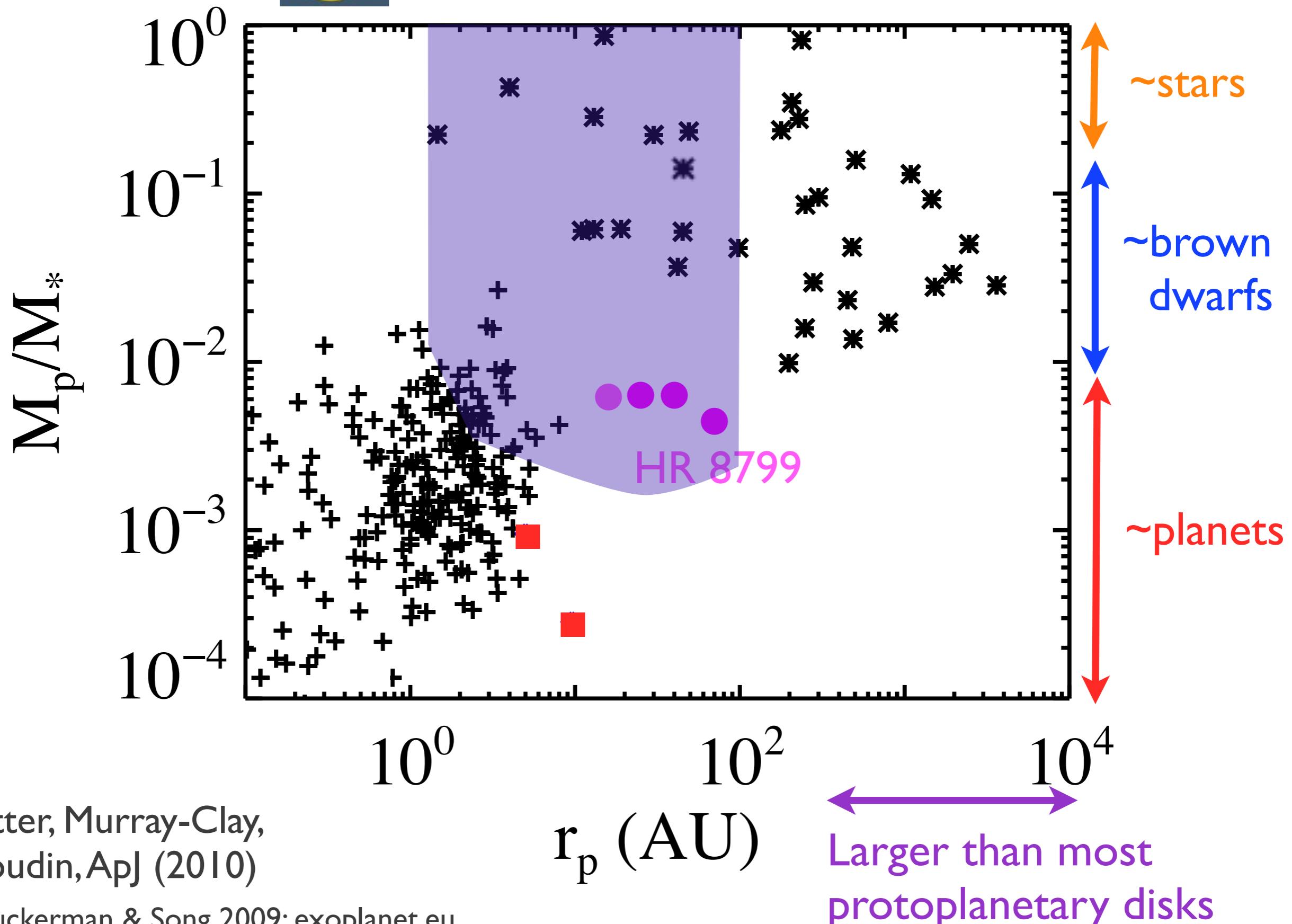
Test case HR 8799: Brown Dwarfs or Planets?

Brown dwarf companions





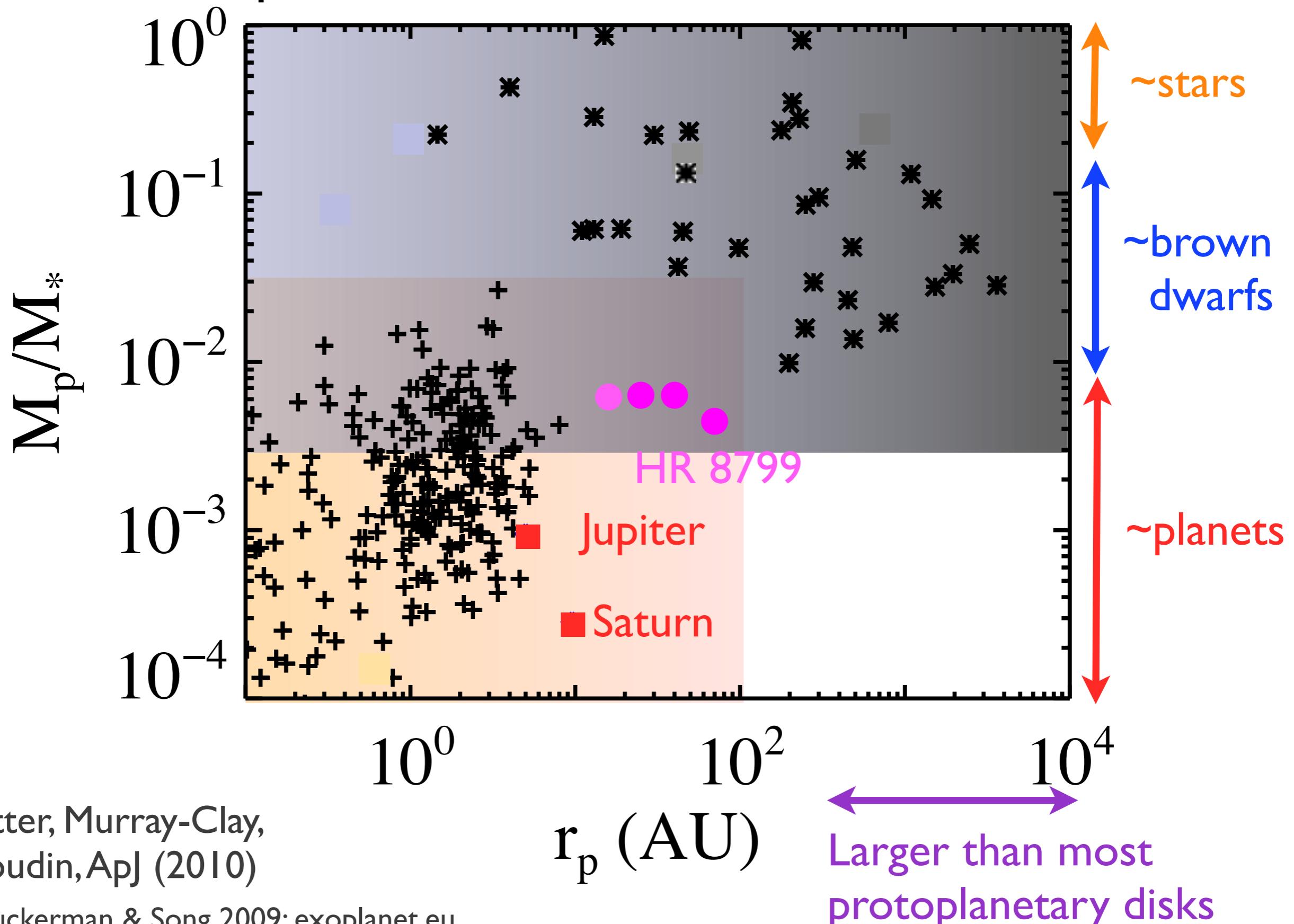
Gemini Planet Imager (PI: Bruce Macintosh)



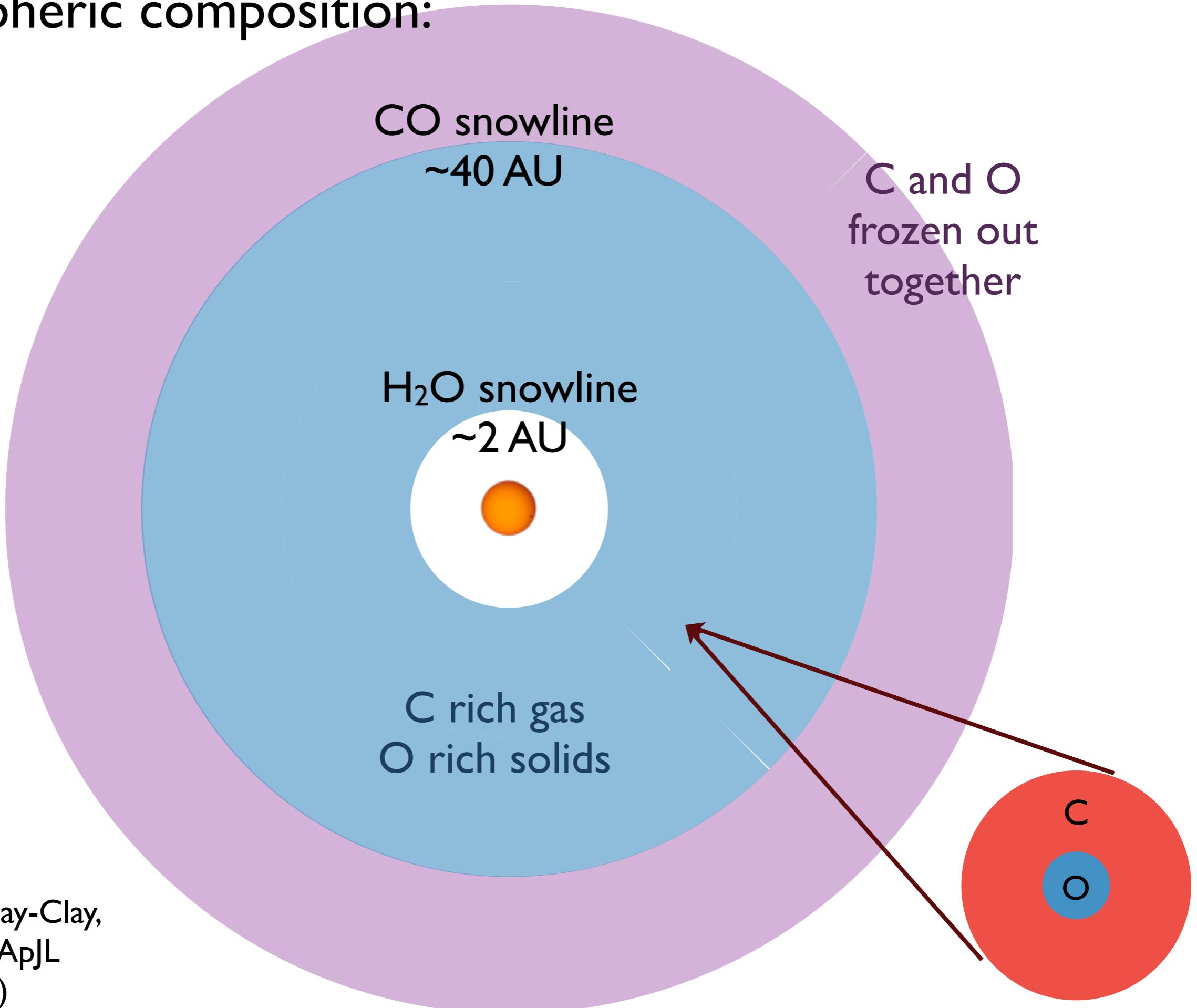
Kratter, Murray-Clay,
& Youdin, ApJ (2010)

Data: Zuckerman & Song 2009; exoplanet.eu

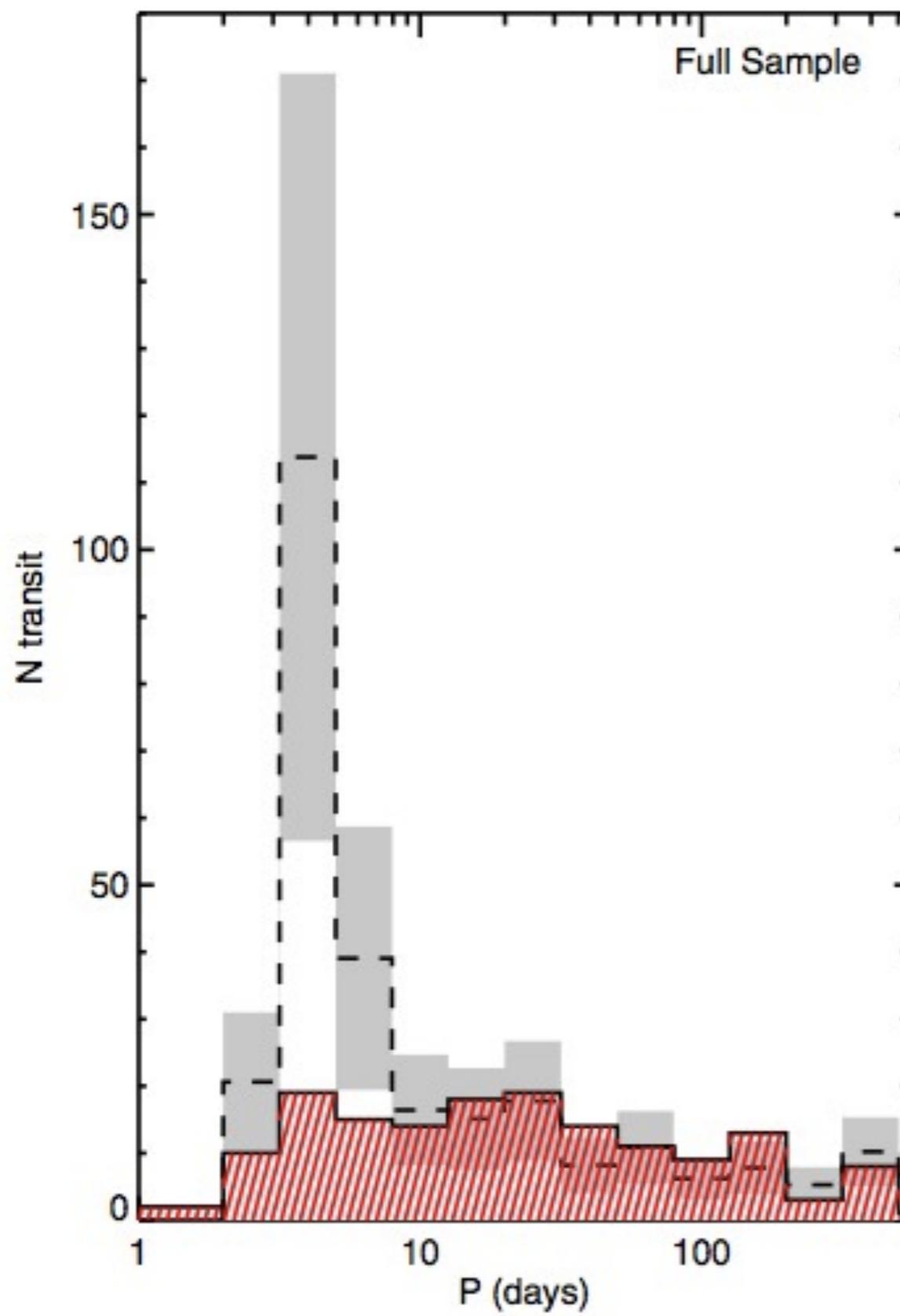
Planetary atmospheric composition and stellar metallicity provide additional discriminants



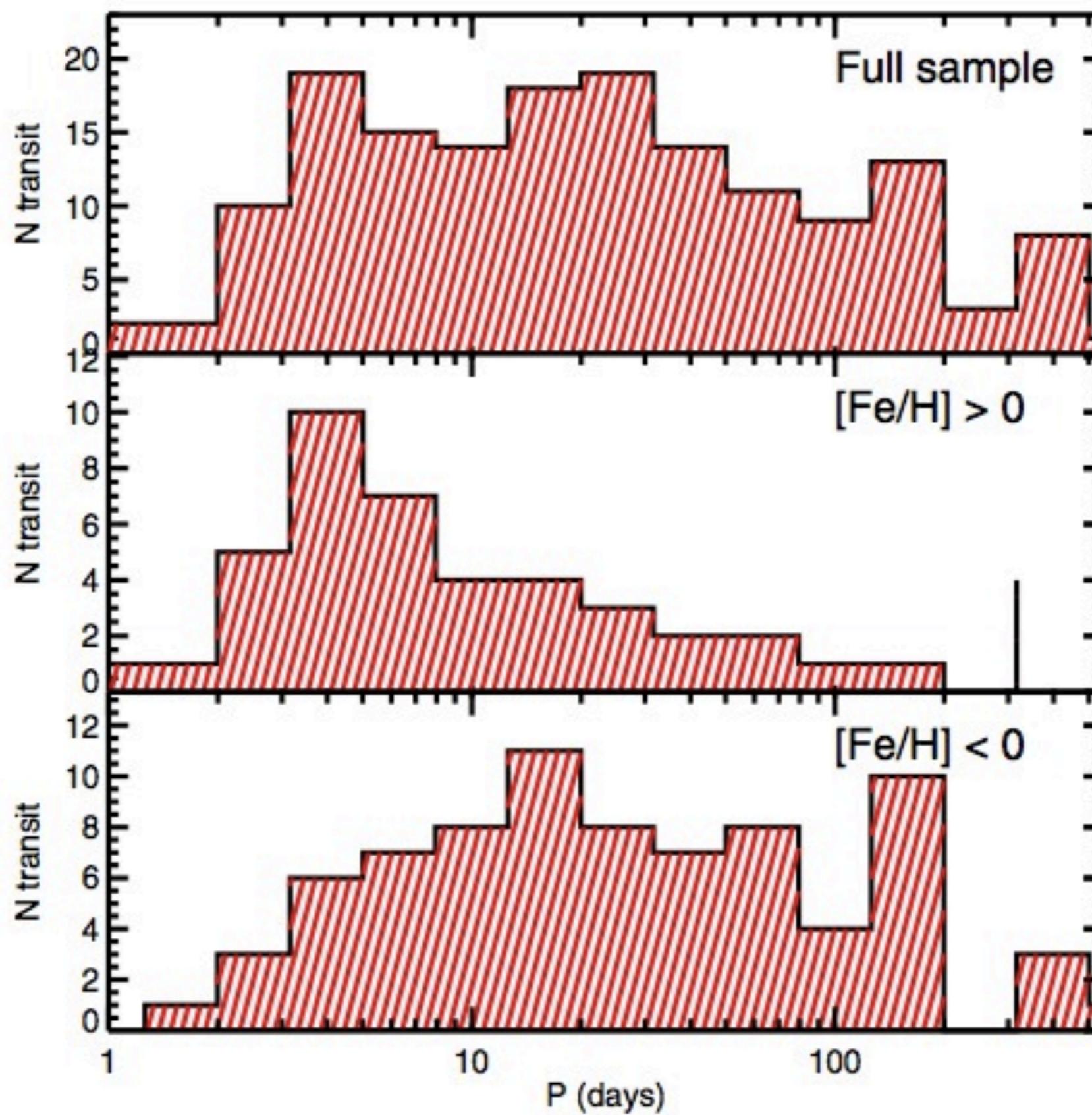
Atmospheric composition:



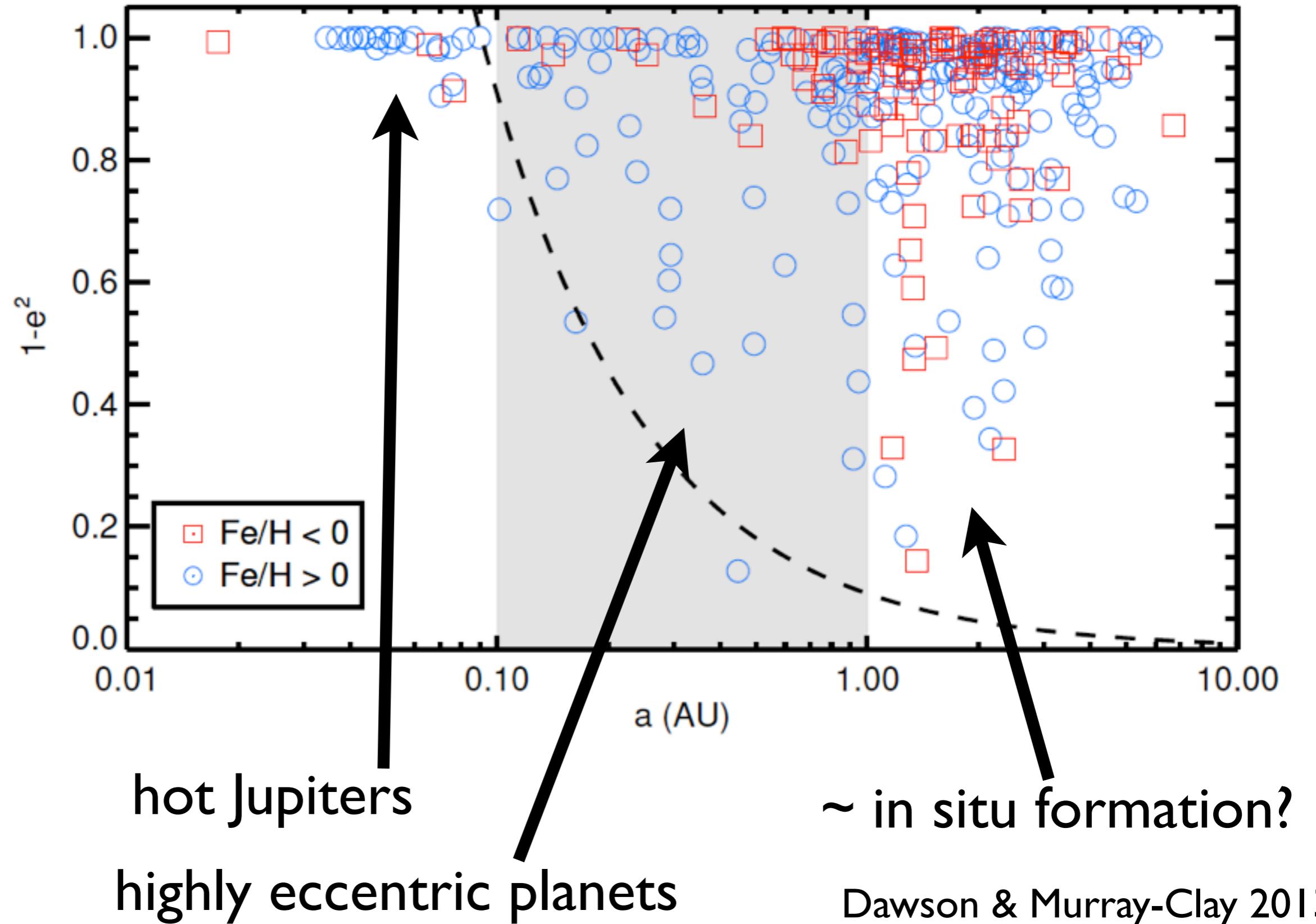
Metallicity:



A hot Jupiter “pile-up” exists in the radial velocity planet sample, but not the Kepler transit sample.

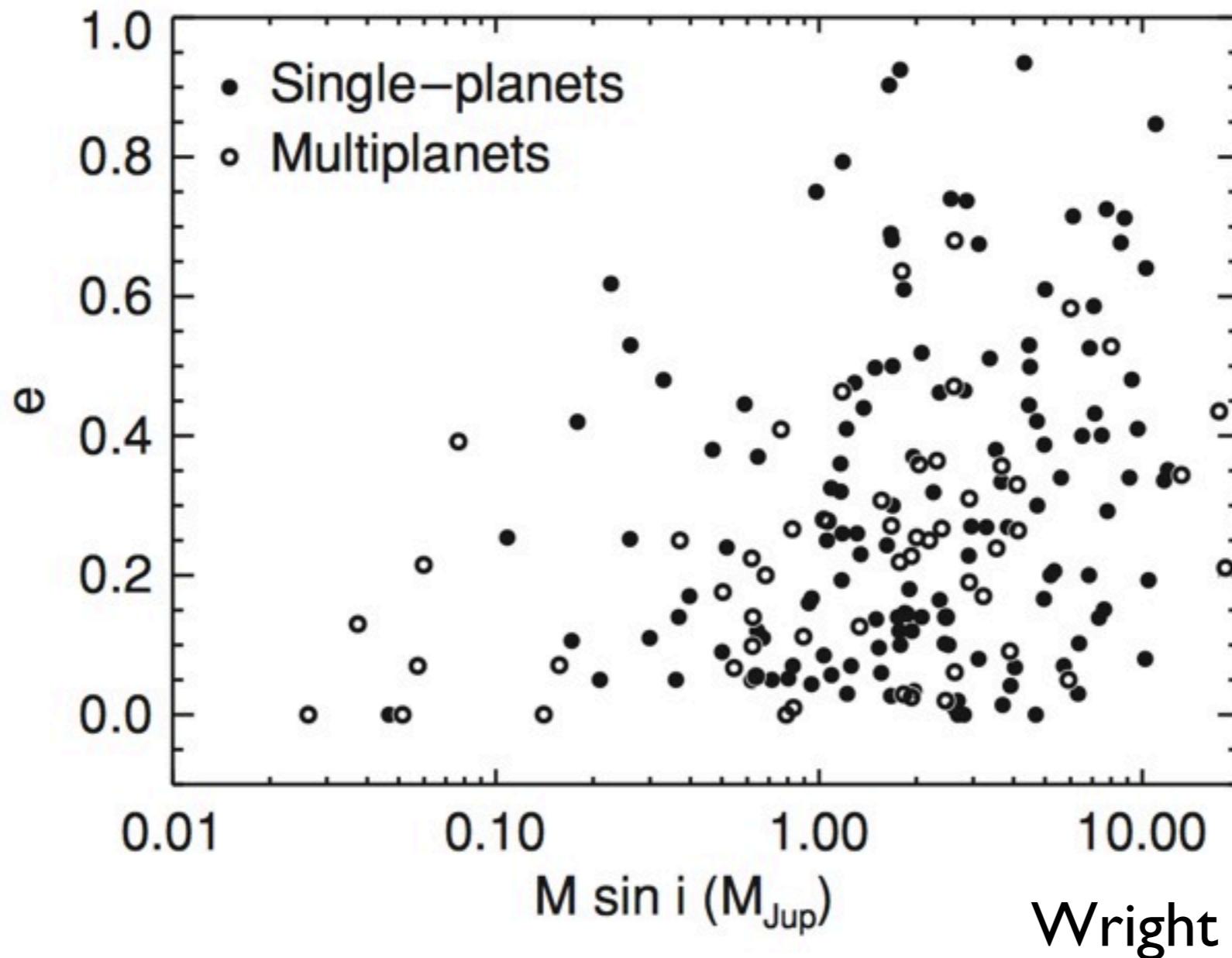


Metal-rich stars host more hot Jupiters and highly eccentric planets: A signature of planet-planet interactions



Are the solar system analogs orbiting low metallicity stars?

High eccentricity via scattering requires scattered objects



Summary

- Are the HR 8799 giant planets (core accretion) or failed brown dwarfs (gravitational instability)?
- Do abundances in the envelopes of gas giants differ from those in their host stars?
- Are the solar system analogs orbiting low-metallicity stars?
- We should see scattered Jupiters.

Test case HR 8799: Brown Dwarfs or Planets?

